

# Complex Mixtures in Industrial Workspaces: Lessons for Indoor Air Quality Evaluations

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Acceptable occupational exposure levels for hundreds of airborne concentrations of dusts, vapors, fumes, and gases have been set by consensus organizations and regulatory bodies for decades. These levels have established tremendous precedent and are tempting reference values in the relatively new field of indoor air quality evaluations where validated criteria are greatly needed. The American Conference of Government Industrial Hygienists (ACGIH) has been the most visible and productive group setting these guidelines for industrial exposure. The ACGIH Chemical Substances Committee has published an annual list of threshold limit values (TLVs) for more than 40 years. Currently the list covers more than 400 substances.

In 1989, the Occupational Safety and Health Administration (OSHA) published updated permissible exposure limits (PELs) for approximately 600 substances. Most PELs before this update were adopted from the 1968 ACGIH list of TLVs and consensus standards of the American Standards Association. This OSHA update has resulted in reductions of 212 PELs and the addition of 164 new levels. The magnitude of the problem of protecting workers can be seen by the small fraction that the OSHA PELs represent of the more than 60,000 entries in the National Institute for Occupational Safety and Health's Registry of Toxic Effects of Chemical Substances. None of these levels, whether guidelines or regulatory requirements, are established based on any possible synergistic effect with other chemicals. The only guidance given by the ACGIH for synergistic effects is that such cases must be determined individually. Clearly, there are major drawbacks in using occupational standards and guidelines for evaluating the health effects of chemical agents that can be found in office settings, often in concentrations orders of magnitude less than what is routinely measured in the workplace. These guidelines are even less valuable when the concern is the complex mixing of chemicals in nonoccupational environments.

## Introduction

### Setting Occupational Standards

Acceptable occupational exposure levels for hundreds of airborne concentrations of dusts, vapors, fumes, and gases have been set by consensus organizations and regulatory bodies for decades. The American Conference of Governmental Industrial Hygienists (ACGIH) has been the most visible and productive group setting these guidelines for industrial exposure. The ACGIH Chemical Substances Committee began its work in 1944 and has published an annual list of threshold limit values (TLVs) for more than 40 years. Currently the list covers more than 400 substances.

The American Industrial Hygiene Association has similarly set workplace environmental exposure limits (WEELs) for many industrial chemicals, as has the American National Standards Institute. Internationally, the World Health Organization and most governments have set occupational exposure limits. Most of these limits are based on a time-weighted average exposure for a period of 8 hr.

In the U.S., the National Institute for Occupational Safety and Health (NIOSH) has the mandate to comprehensively review the research on a specific workplace toxin and then recommend a level that should be set by the Occupational Safety and Health Administration (OSHA) as a regulatory standard for airborne concentration: the permissible exposure limit (PEL). The threshold limit values have been a much more significant influence on the PELs than the recommendations of NIOSH. The reasons are primarily historical. NIOSH and OSHA were created by the Congress at the same time. OSHA, with the responsibility for establishing workplace standards, could not wait for NIOSH to complete the lengthy scientific reviews. Consequently, shortly after its creation in 1970, OSHA adopted the 1968 TLVs, which were intended as guidelines, and made them regulatory PELs.

### Use of Occupational Standards for Nonoccupational Settings

The ACGIH has always indicated that, "These limits are intended for use in the practice of industrial hygiene as guidelines or recommendations in the control of potential health hazards and for no other use, e.g., in the evaluation or control of community air pollution nuisances, in estimating the toxic potential of continuous, uninterrupted exposures or other extended work

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periods" (1). This caveat has not dissuaded many air pollution control agencies throughout the country from setting outdoor levels at one-tenth of TLV limits. This concept of setting limits for nonoccupational environments at one-tenth of the occupational level has also become firmly integrated into indoor air quality investigations. The new American Society of Heating, Refrigerating and Air Conditioning Engineers Standard (ASHRAEQ 62-1989) entitled "Ventilating for Acceptable Indoor Air Quality" (2) refers to occupational standards as part of the decision criteria under the ventilation rate procedure. This new standard has become one of the most important guidance documents on indoor air quality. This is particularly true for engineers and designers. Consequently, the use of occupational standards to evaluate the acceptability of air quality in office buildings will continue.

## Limitations of Occupational Standards

### Concept of the Time-Weighted Average

The concept of time-weighted average (TWA) is widely used as an index of exposure and dose. Occupational standards are also expressed as ceiling values and short-term exposure values of a half hour or less duration, but for the majority of the new OSHA PELs, there is only a TWA listing.

The use of TWA was first described in 1933 by Bloomfield, who spoke of "true average dust exposure" (3). Yant (4) warned against the use of single values as an index of exposure. Simple averages or integrations of the time and concentration of exposure may be expedient, but they may produce erroneous results because toxicological response cannot be expected to be a linear function of time and concentration. Even more importantly, the amplitude and frequency of variation from the mean value may be very critical data. Much later, MacFarland (5) emphasized the difference between exposure and true dose. Exposure corresponds to milligram-minutes per cubic meter of atmospheric air; true dose corresponds to grams per kilogram of body weight.

Savolainen and co-workers (6) studied the body burden of dichloromethane in rats exposed to various TWAs of the vapor. They concluded that, for the same 8-hr average, exposure to peaks of high concentration produced larger burdens and neurochemical effects than comparable exposure to stable concentrations of dichloromethane. In other words, exposures to the same TWA concentration can produce different physiological responses.

Atherly (3) noted that TWA as an index of exposure has been relied on extensively for legislation and research and has often been designated as an index of dose. Atherly (3) stressed the need that future research carefully distinguish between dose and exposure. He further stated that the TWA concept cannot be viewed as a scientific idea based on either empirical evidence or plausible scientific hypothesis.

## Criticisms of the Threshold Limit Values

### Adequacy of the Research for the TLVs

According to the most recent book of TLVs (1), the ACGIH committees base their TLVs on the "best available information from industrial experience, from experimental human and animal studies, and, when possible, from a combination of the

three. The basis on which the values are established may differ from substance to substance; consequently, the precision of the estimated TLV is also subject to variation."

Castleman (7) refuted the idea that TLVs are based on the best available information. He examined the documentation for the TLVs and claimed that for a total of 89 substances, the 1986 TLV documentation placed major reliance on unpublished corporate communications with an additional 15 substances assigned threshold levels solely on the basis of unpublished corporate studies.

As an example, the 1986 documentation for morpholine referenced a 1963 text by George Patty as a basis for stating that no chronic effects had been reported (7). The primary source cited by Patty was a 1948 review on morpholine issued by the American Petroleum Institute.

### Acute Effects

The 1968 TLVs were set primarily for acute, not chronic, effects of toxicity (8). The concern for upper respiratory tract irritation in industry for a worker exposed primarily to one chemical in a particular industrial process is quite different from the typical office environment with indoor air quality problems where many agents may be mixing at much lower concentrations. Most of the TLVs do not reflect long-term health effects such as cancer, reproductive damage, or hard-to-pinpoint illnesses such as fatigue, headaches, or slowed nerve-conduction response time.

### Average Person

TLVs refer to airborne concentrations of substances and represent conditions under which the ACGIH committee believes that nearly all workers may be repeatedly exposed without adverse effect. The committee concedes that a small percentage may experience discomfort at levels below the TLV and that a smaller percentage may be more seriously affected. The potential of hypersusceptibility is also given credence by the committee.

Most importantly, the committee noted that these limits are intended as guidelines for industrial hygiene practice, not as regulations or for estimating toxic potential of continuous, uninterrupted exposures (1). They are not fine lines between safe and dangerous nor are they a relative index of toxicity. The limitations here are obvious for indoor air quality investigations. Many investigations involve only a few of the occupants. The TLVs were admittedly set for average people, yet we find elderly, asthmatics, and truly hypersensitive people in office settings.

## Problem with Complex Mixtures

### Lack of Research

In March 1989, OSHA published updated PELs for approximately 600 substances. Most PELs before this update were adopted from the 1968 ACGIH list of TLVs and consensus standards of the American Standards Association.

This OSHA update is important and has resulted in reductions of 212 PELs and the addition of 164 new levels. But the magnitude of the problem of protecting workers can be seen by the small fraction that the OSHA PELs represent of the more than 60,000

entries in the National Institute for Occupational Safety and Health's Registry of Toxic Effects of Chemical Substances.

Some research has been conducted on synergistic effects in workplace environments, but it is woefully inadequate. Of the more than 100,000 references to occupational toxicology in the *Toxline* database, only 20 referred to synergistic effects.

The National Institute for Occupational Safety and Health noted in its 1975 Criteria Document on carbon tetrachloride (9) that more extensive damage to the liver can be expected if ethyl alcohol is ingested too. None of the occupational levels, whether guidelines or regulatory requirements, are established based on any possible synergistic effect from other chemicals.

## Use of the Mixture Formula

The ACGIH does have a policy for dealing with mixing of chemicals. If chemicals act on the same organ system, their combined effect should be given primary consideration. Without any data to the contrary, one assumes the effects to be additive and uses the following formula:

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \dots + \frac{C_n}{T_n}$$

where  $C$  is the measured concentration, and  $T$  is the threshold limit for that chemical. Any result greater than unity indicates that the limit has been exceeded.

This same approach is part of the regulatory requirements set by OSHA and can be found in its latest document on the updated permissible exposure limits (10). Clearly, this approach does not deal with synergism at all.

## Different Forms of the Same Chemical

Complicating the picture even more is the fact that different forms of the same chemical can produce strikingly different responses. Formaldehyde is a classic example. Frigas and associates (11) reported on a patient who developed severe asthma after her house was insulated with urea formaldehyde foam insulation. Her symptoms worsened at night. Although bronchial challenge with the fine dust of the foam caused an asthmatic attack within 1 hr, the inhalation of 3 ppm formaldehyde in a closed system for 8 min, did not produce the same response. Other researchers (12) reported that, in the presence of suitably sized particles as carriers, formaldehyde can be taken into the lung where it stimulates bronchial reaction more than if it were in the upper respiratory tract.

Gilli and co-workers (13) have shown that there may be a relationship between the formaldehyde content of dust and health ef-

fects. Although levels of free formaldehyde in air ranged only from 60 to 80 ppb, the content in respirable dust ranged from 4150 to 6250 ppm.

## Conclusions

Occupational exposure levels have established tremendous precedent and are tempting reference values in the relatively new field of indoor air quality evaluations where validated criteria are greatly needed. Clearly, there are major drawbacks in using occupational standards and guidelines for evaluating the health effects of chemical agents that can be found in office settings, often in concentrations orders of magnitude less than what is routinely measured in the workplace. These guidelines are even less valuable when the concern is the complex mixing of chemicals in nonoccupational environments.

## REFERENCES

1. ACGIH. Threshold Limit Values and Biological Exposure Indices. American Conference of Government and Industrial Hygienists, Cincinnati, OH, 1990, pp. 3-4.
2. ASHRAE. Ventilation for Acceptable Indoor Air Quality, ASHRAE 62-1989. American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, 1989, p. 17.
3. Atherley, G. A critical review of time-weighted average as an index of exposure and dose, and of its key elements. *Am. Ind. Hyg. Assoc. J.* 46(9): 481-487 (1985).
4. Yant, W. P. Industrial Hygiene Codes and Regulations. Industrial Hygiene Foundation Transactions of 13th Annual Meeting, Pittsburgh, PA, November 13, 1948, pp. 48-61.
5. MacFarland, H. Respiratory toxicology. In: *Essays in Toxicology*. Academic Press, New York, 1976, pp. 121-154.
6. Savolainen, H., Kurppa, K., Pfaffli, P., and Kivisto, H. Dose-related effects of dichloromethane on rat brain in short-term inhalation exposure. *Chem.-Biol. Interact.* 34: 315-322 (1981).
7. Castleman, B. Corporate influence on threshold limit values. *Am. J. Ind. Med.* 13: 531-559 (1988).
8. Clark, N., Cutter, T., and McGrane, J. *Ventilation: A Practical Guide for Artists, Craftspeople, and Others in the Arts*. Nick Lyon Books, New York, 1984, p. 10.
9. NIOSH. Criteria for a Recommended Standard on Occupational Exposure to Carbon Tetrachloride. National Institute of Occupational Safety and Health, Washington, DC, 1975, pp. 61-69.
10. OSHA. Permissible Exposure Limits, Title 29 CFR 1910.1000. Occupational Safety and Health Administration, Washington, DC.
11. Frigas, E., Filley, W. V., and Reed, C. E. Asthma induced by dust from urea formaldehyde foam insulating material. *Chest* 79: 706 (1981).
12. Labelle, C. W., Long, J. E., and Cristofano, E. E. Synergistic effects of aerosols. *Arch. Ind. Health* 11: 297 (1981).
13. Gilli, G., Corrado, E., and Scursatone, E. Dust as a carrier of formaldehyde: low environmental concentrations and allergic phenomena. *Tubercula* 78: 101 (1981).